Chapter 1
Introduction

1-1. Purpose

This manual provides practical guidance for the design and operation of soil vapor extraction (SVE) and bioventing (BV) systems. It is intended for use by engineers, geologists, hydrogeologists, and soil scientists, chemists, project managers, and others who possess a technical education and some design experience but only the broadest familiarity with SVE or BV systems.

1-2. Applicability

This manual applies to HQUSACE elements, major subordinate commands (MSC), districts, laboratories, and field operating activities (FOA) having hazardous, toxic, or radioactive waste responsibilities.

1-3. References

The manual does not present a detailed, comprehensive discussion of each and every factor associated with SVE or BV systems. Such a presentation would require many volumes. However, there are several publications which provide excellent summaries of design factors and operational details. An extensive listing of books and journal articles pertaining to SVE and BV is presented in Appendix A. Of these references, the following are suggested as key supplementary sources of information for design and operation of SVE or BV systems.

Subject	**Reference**
Technology overview	Holbrook et al. 1998
	Johnson et al. 1994
	USEPA 1989a
	USEPA 1991d
	USEPA 1992a
	USEPA 1995b

Important physical, biological, and chemical parameters	ASTM D5126-90 Corey 1986a DePaoli et al. 1991c Downey and Hall 1994 Johnson, Kemblowski, and Colthart 1990b Ostendorf and Kampbell 1991 USEPA 1986 USEPA 1991c
Pilot testing and design	DiGuilio et al. 1990 Hinchee et al. 1992 Holbrook et al. 1998 Johnson et al. 1990a Johnson and Ettinger 1994 Sayles et al. 1992 US EPA 1995a
Modeling	Baehr, Hoag, and Marley 1989 Becket and Huntley 1994 DePaoli et al. 1991b DePaoli et al. 1991c Falta, Pruess, and Chestnut 1993 King 1968 Marley et al. 1990a Massmann 1989 McWhorter 1990 Muskat and Botset 1931 Rathfelder, Yeh, and Mackay 1991 Shan, Falta, and Javandel 1992 USEPA 1993c Wilson, Clarke, and Clarke 1988
Equipment specification and operation	DePaoli et al. 1991b Johnson et al. 1990a USEPA 1992a USEPA 1993c

Evaluation of system performance	CEGS 01810 Commissioning and Demonstration for Soil Vapor Extraction (SVE) Systems CEGS 02150 Piping; Off-Gas CEGS 11215 Fans/Blowers/Pumps; Off-Gas DePaoli et al. 1991b DePaoli et al. 1991c Holbrook et al. 1998 Peargin and Mohr 1994 Travis and Macinnis 1992 USEPA 1989a USEPA 1989b USEPA 1990a USEPA 1992a
Associated Technologies and Enhancements	In-Situ Air Sparging: USACE EM 1110-1-4005 Air Sparging: Holbrook, et. al. 1998 Multi-Phase Extraction: USACE EM 1110-1-4010 Enhancements: USEPA 1997a, 1997b

Additional, updated references are available on the internet, including the following website maintained by the USACE: http://www.environmental.usace.army.mil/info/technical/geotech/sve/sve.html

There are many periodicals that frequently include research and case studies pertaining to SVE and BV. Some of these are:

Environmental Protection;
Environmental Science and Technology;
Ground Water (Association of Ground Water Scientists and Engineers);
Ground Water Monitoring and Remediation (Association of Ground Water Scientists and Engineers);
Hazardous Materials Control;
Hazardous Waste and Hazardous Materials;
Journal of Contaminant Hydrology;
Journal of Environmental Engineering (American Society of Civil Engineers);
Journal of Hazardous Materials;
Pollution Engineering;
Remediation, Journal of Environmental Cleanup Cost, Technologies & Techniques;
The National Environmental Journal; and
Water Resources Research (American Geophysical Union).

1-4. Background

Groundwater contamination by petroleum products and organic solvents is a serious problem in industrialized countries. Underground petroleum storage tanks (USTs) account for a large portion of the problem. In 1993, the U.S. Environmental Protection Agency (USEPA) estimated that of the 2 million USTs in the United States, more than 10 percent, or about 295,000, are leaking (USEPA 1993a). In addition, surface spills, pipeline leaks, and releases from pits, ponds, and lagoons have contributed to this contamination problem.

a. Residual volatile organic compounds (VOCs) constitute an ongoing source of contamination of soil and groundwater. Emphasis has recently been placed on removing this long-term contamination source in addition to mitigating immediate effects. In situ solutions are also increasingly favored for their economic advantages.

b. SVE is one of the most effective and cost-efficient methods of removing VOCs from unsaturated soils. An SVE system consists of one or more extraction wells screened in the unsaturated zone, blowers or vacuum pumps, and often also includes air injection or pressure venting wells, a low permeability cap at the ground surface, an air/water separator, and an offgas treatment system.

c. Airflow is induced in the unsaturated zone by creating a pressure gradient through the injection or withdrawal of air from wells or trenches in the subsurface. SVE systems usually withdraw air for subsequent treatment by adsorption on granular activated carbon (GAC), catalytic oxidation, or other processes. The SVE gas flow enhances evaporation of nonaqueous phase liquids (NAPL), volatilization of contaminants dissolved in pore water, and desorption of contaminants from the surfaces of soil particles.

d. Major limitations of SVE are the need, at some locations, for offgas treatment, and the inability to extract semivolatile organic compounds (SVOCs) (Dupont, Doucette, and Hinchee 1991; USEPA 1988a). Costs for offgas treatment can exceed 50 percent of total SVE remediation costs (Reisinger, Johnstone, and Hubbard 1994).

e. BV is similar to SVE in that air is made to flow through the subsurface, but treatment of contaminants takes place in situ rather than aboveground, thereby reducing remediation costs. Naturally occurring microorganisms in the unsaturated zone biodegrade the contaminants. BV airflow rates need to be sufficient to provide oxygen to the microorganisms, which are usually oxygen limited, but slow enough to allow sufficient contaminant residence times in the subsurface and minimize volatilization losses to areas outside the treatment zone. BV does not rely on volatilization, and therefore is appropriate for semi-volatile compounds that are aerobically biodegradable, as it focuses on the treatment of soil contaminants and soil vapors within the unsaturated zone prior to their release to the atmosphere. A BV system consists of one or more extraction or injection wells screened in the unsaturated zone, blowers or vacuum pumps, and often also includes air injection or pressure venting wells.

f. In the United States, SVE is an accepted technology that has been used at landfill sites and at leaking UST sites since the 1970s. As early as 1972, Duane Knopik began employing SVE to clean up leaked gasoline from a UST at his service station in Forest Lake, Minnesota. By 1982, Knopik had employed his by then-patented system (see paragraph 11-2) at approximately 100 installations throughout the United States. Other early developers of SVE systems in the late 1970s and early 1980s included Oil Recovery Systems, Exxon Company USA, Shell Oil Company, Upjohn Company, and the American

Petroleum Institute (Thornton and Wootan 1982; U.S. District Court 1994). Soil venting, which includes air extraction and injection, is the primary method used in the United States to remove VOCs from the unsaturated subsurface. SVE, which always involves air extraction but may include air injection, is considered a presumptive remedy for VOCs in the USEPA's Superfund program, meaning that a detailed technology screening process is not necessary for implementation. In 1997, SVE was applied or planned to be applied at 27% of Superfund sites (USEPA 1999). Since this statistic does not include bioventing, application of venting (i.e., including both SVE and bioventing) at Superfund sites likely exceeds 30%. Thus, its frequency of use if second only to groundwater pump and treat. A majority (69 percent) of the total volume of soil at Superfund remediation actions is treated by SVE (USEPA 1999). The popularity and widespread use of venting is due to its simplicity of operation and proven ability to remove contaminant mass inexpensively compared to competing technologies.

g. Evidence of unsaturated zone biodegradation resulting from air advection was first reported by the Texas Research Institute (1980; 1984). During the same period, researchers conducting experiments for Shell Research in the Netherlands made the first field observations of venting-induced biodegradation (van Eyk and Vreeken 1988). In the late 1980s and early 1990s, the U.S. Air Force (USAF) carried out field-scale SVE and bioventing research at several bases, including Hill AFB in Utah and Tyndall AFB in Florida (DePaoli et al. 1991a, 1991b, 1999c; Miller et al. 1991). This work was expanded to include bioventing testing at >125 sites, in an effort the Air Force Center for Environmental Excellence (AFCEE) termed their Bioventing Initiative (Miller et al. 1993; AFCEE 1996). The USAF now considers bioventing to be a presumptive remedy for jet fuel-contaminated sites.

1-5. Scope

This manual deals with all aspects of the engineering of SVE/BV systems, including site characterization, technology selection, bench- and pilot-scale testing, design, installation, operation, and closure.

a. When this Engineer Manual was first prepared in 1995, SVE and BV were relatively new technologies. The basic physical principles governing SVE are fairly well understood, but details of system design were, and still are often determined empirically rather than by rigorous analysis (Massmann 1989; Johnson et al. 1990a). This document attempts to normalize the approach to design and implementation of SVE/BV. Since 1995, several important documents have been published expanding the knowledge base for this technology. These include:

- A WASTECH monograph entitled Vapor Extraction and Air Sparging (Holbrook et al. 1998) was authored by some of the leading authorities on air based remediation systems. WASTECH is a multiorganization effort which joins in partnership professions, societies of soil scientists, microbiologists, and chemical, civil and mechanical engineers; U.S. EPA, DOD, and DOE; and a number of other organization that address hazardous waste issues. This monograph, sponsored in part by U.S. EPA's Technology Innovation Office covers the design, applications and implementation of SVE, bioventing and air sparging. It places particular emphasis on enhancements to these technologies.

- Recommendations stemming from AFCEE's Bioventing Initiative are provided as guidance in Principles and Practices of Bioventing (Leeson and Hinchee 1995). AFCEE has included in this document guidance from their extensive experience from performing and monitoring BV at hundreds of sites.

- U.S. EPA's "Analysis of Selected Enhancements for Soil Vapor Extraction" (USEPA 1997a), a comprehensive engineering report describing the status of and evaluating Air Sparging, Dual-Phase Extraction, Direction Drilling, Pneumatic and Hydraulic Fracturing, and Thermal Enhancements as methods for aiding remediation of sites otherwise addressed by SVE.

- USACE's Engineer Manuals on In Situ Air Sparging (1110-1-4005) and Multi-Phase Extraction (1110-1-4010). These manuals, discussed briefly in this manual, expand upon the engineering guidance provided in the original SVE/BV EM by describing the physics and application of these related air based remediation technologies.

b. This SVE/BV EM intends to capture the advances of the state-of-the-science that have been presented in the foregoing documents and in the peer reviewed literature to upgrade the engineering guidance originally developed in 1995.

c. Although various models are discussed within pertinent sections, exhaustive coverage of analytical and numerical modeling relevant to SVE and BV systems is beyond the scope of the manual. Information on a wide range of available models is summarized in Appendix C.

1-6. Organization

a. The manual is intended to be as helpful as possible to the designer/operator of SVE/BV systems. Material is organized sequentially, so that the reader can conveniently begin using it at any stage of an SVE/BV project. It is recommended that regardless of the stage of the project at hand, Chapter 3 be reviewed first if there is any question as to whether selection of SVE/BV at a given site is appropriate. The design process is summarized in a set of decision trees, and case examples are presented for each major topic.

b. The manual provides the guiding principles and thought processes for engineering SVE/BV systems. The numerous site-specific conditions which come into play in any given SVE/BV situation preclude a simple cookbook approach. System design is as much an art as a science, and system modifications are necessary as new information becomes available or site conditions change.

1-7. Tools and Resources

A variety of tools and resources are available to assist the SVE and BV practitioner. These include models for design and optimization of systems, technical journals and publications which summarize case studies and recent technical developments, and electronic bulletin boards which summarize technical developments and vendor information. New SVE and BV techniques are continually being developed. Therefore, a review of the latest case studies, models, and references prior to designing an SVE/BV system is recommended.

a. Models. Analytical and numerical models can be used to:

- Determine applicability of various SVE and BV configurations during the technology screening process.

- Aid in design of pilot test programs.

- Extrapolate pilot test data to design of full-scale systems.

- Estimate airflow rates and contaminant concentrations to aid in equipment specification.

- Optimize the numbers and locations of air extraction and injection points.

- Estimate the time that will be required to meet remedial objectives.

- For BV, determine kinetic parameters of biodegradation.

(1) Models should not be used in place of pilot testing because subsurface systems usually include variations in permeability, moisture content, and contaminant concentrations, and may include man-made conduits which are not detected during site investigations and are, therefore, not simulated in models. These variations are frequently detected during the pilot-testing process and become important to the design and successful operation of full-scale systems. Models are also based on specific assumptions (e.g., site homogeneity, boundary conditions, absence of layers) that do not match site conditions.

(2) Models range from commercially available, user friendly computer programs to complicated, uncompiled computer code requiring substantial programming ability. Models may be divided into three categories:

- Models that simulate pressure distributions and airflow.

- Models that simulate contaminant, oxygen, and other vapor concentrations.

- Models that simulate both pressure distributions and vapor concentrations.

(3) Reference will be made throughout the manual, where appropriate, to models that may be useful for the task being discussed. Appendix C summarizes the models that are currently available, including their applications, limitations, and ease of use.

b. Other useful sources of information. Computer databases, electronic bulletin board systems (BBS), and expert systems are available to provide information on the latest remediation technology developments, available software, and new publications.

(1) Several offices and technical laboratories within the USEPA provide special computer bulletin boards related to soil and groundwater remediation technologies. Specifically, the USEPA, Office of Research and Development (ORD: Cincinnati, Ohio) offers a BBS called CLU-IN that provides access to forums, databases, modeling software, and technical articles on innovative technologies for soil and groundwater remediation at Superfund sites. The CLU-IN web site address is http://www.clu-in.org/.

(2) USACE Hazardous, Toxic, and Radioactive Waste Center of Expertise (HTRW-CX) has designed a computer-based information system entitled Lessons Learned. This system was created to facilitate the exchange of information among multidisciplinary USACE elements; to collect ideas on solutions, new technology, and better methods; and to distribute those lessons learned to system users. The database requires a PC with MSDOS v.3.0 or later, with at least 400k available RAM, and 2 megabytes free space, and a modem (Hayes compatible unless file transfers can be accomplished without one). For additional information contact the HTRW-CX staff at:

Web site: http://hq.environmental.usace.army.mil/tools/lessons/list/list.html

(3) Other Federal agencies and research organizations also provide BBS and electronic databases. A number of useful links may be found at the following web site maintained by USACE: http://www.environmental.usace.army.mil/info/technical/geotech/sve/sve.html

(4) The USEPA's RCRA/Superfund Hotline (800-424-9346) is a source of additional information on SVE and BV.